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## (54) PIXEL STRUCTURE OF IMAGE SENSOR HAVING DIELECTRIC LAYER SURROUNDING PHOTO CONVERSION LAYER AND COLOR FILTER

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(60) Continuation of application No. 16/223,247, filed on Dec. 18, 2018, now Pat. No. 10,468,443, which is a division of application No. 15/088,238, filed on Apr. 1, 2016, now Pat. No. 10,177,186, which is a continuation of application No. 14/731,474, filed on Jun. 5, 2015, now Pat. No. 9,356,069, which is a division of application No. 14/014,488, filed on Aug. 30, 2013, now Pat. No. 9,064,989.

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*H01L 31/0232* (2014.01)
*H01L 27/146* (2006.01)

(52) **U.S. Cl.**
CPC .... ***H01L 27/14621*** (2013.01); ***H01L 27/1463*** (2013.01); ***H01L 27/14627*** (2013.01); ***H01L 27/14645*** (2013.01); ***H01L 27/14665*** (2013.01); ***H01L 27/14685*** (2013.01); ***H01L 31/02327*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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*Primary Examiner* — Hung K Vu
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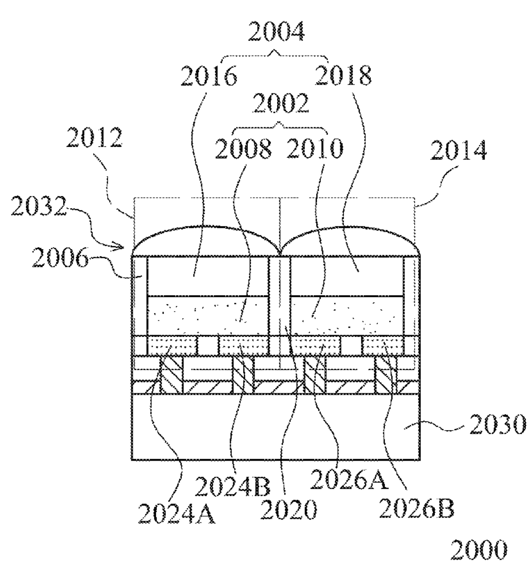
(57) **ABSTRACT**

A photo diode includes a pixel unit, a photo conversion layer, and a dielectric layer. The pixel unit includes a pair of pixels. The photo conversion layer is above the pixel unit and has a pair of portions, each of which corresponds to a respective one of the pixels. The dielectric layer is between the portions of the photo conversion layer. A method of manufacturing the photo diode is also disclosed.

**20 Claims, 17 Drawing Sheets**



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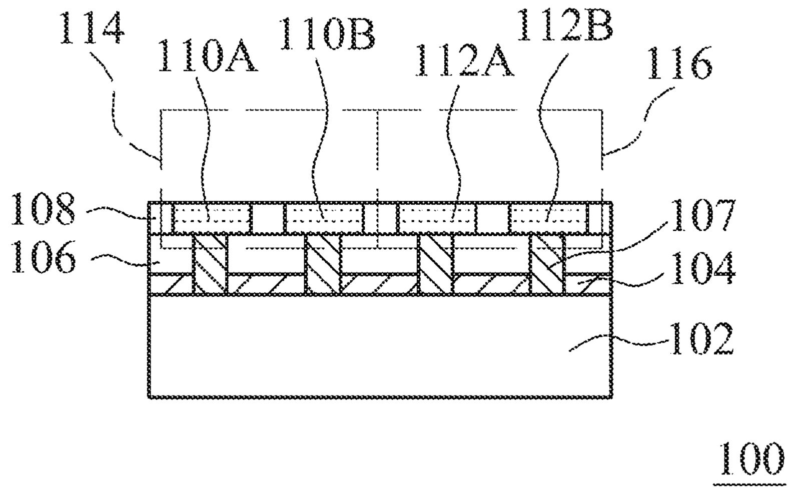

114
110A
110B
112A
112B
116
108
106
107
104
102
100

Fig.1

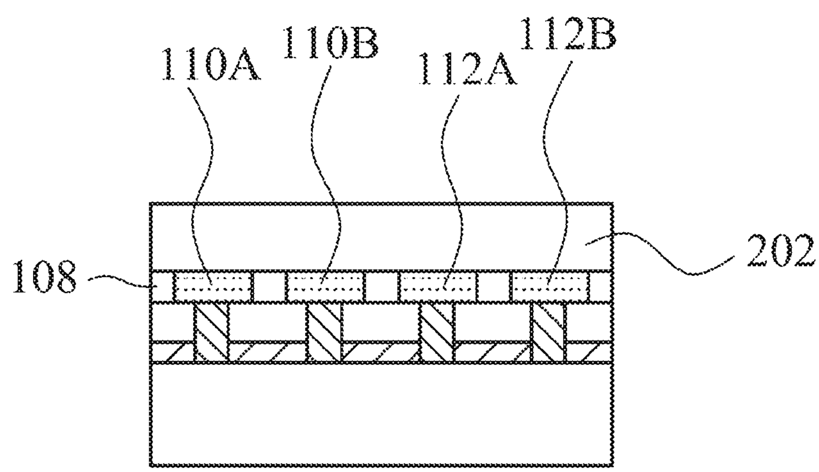

110A
110B
112A
112B
108
202

Fig.2

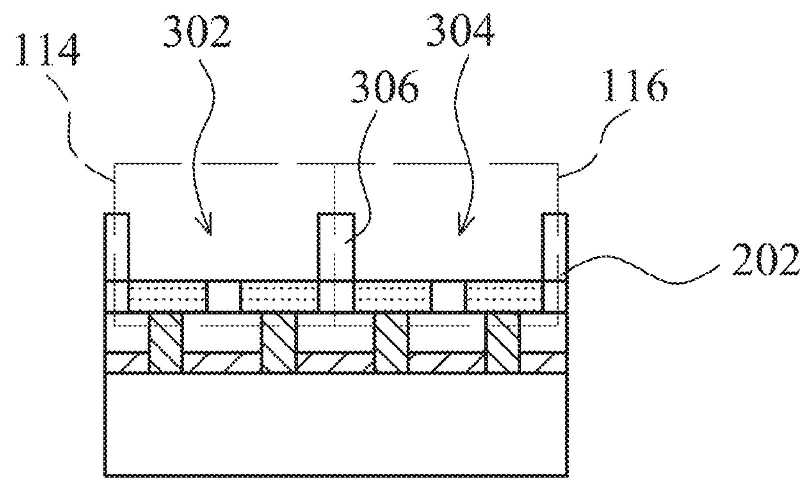

114
302
304
306
116
202

Fig.3

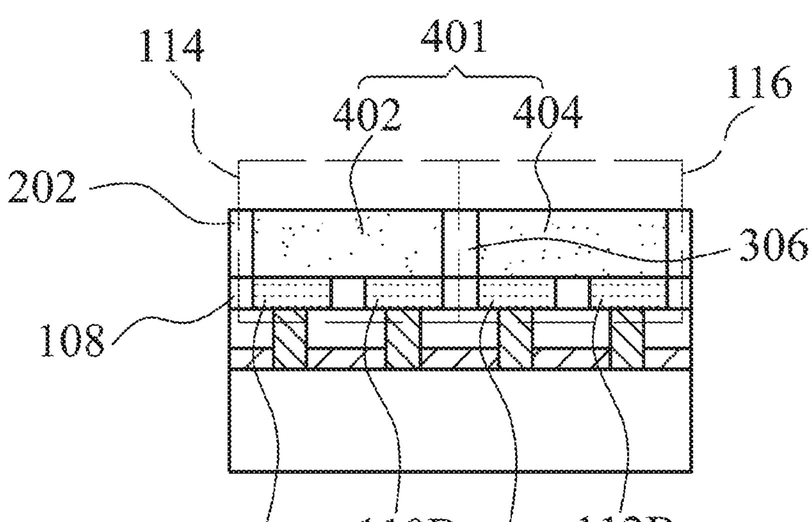

114
401
116
402
404
202
306
108
110A
110B
112A
112B

Fig.4

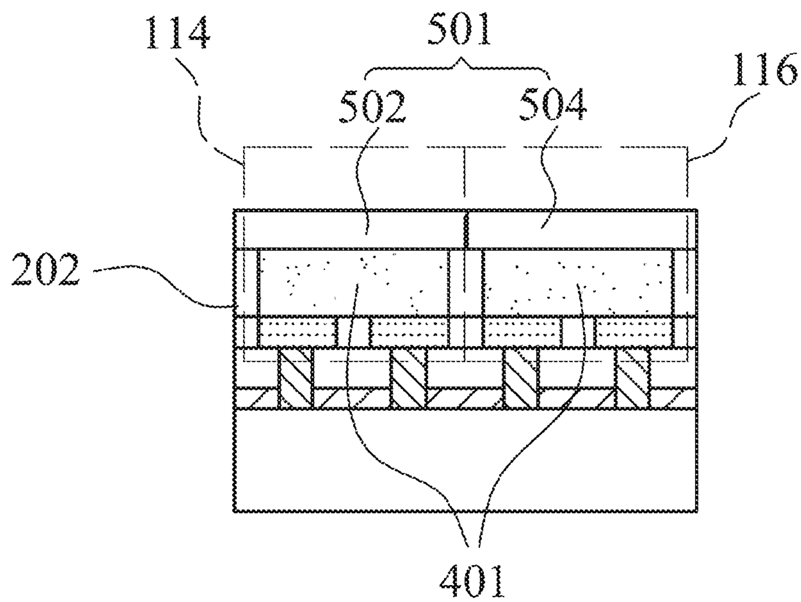



Fig.5

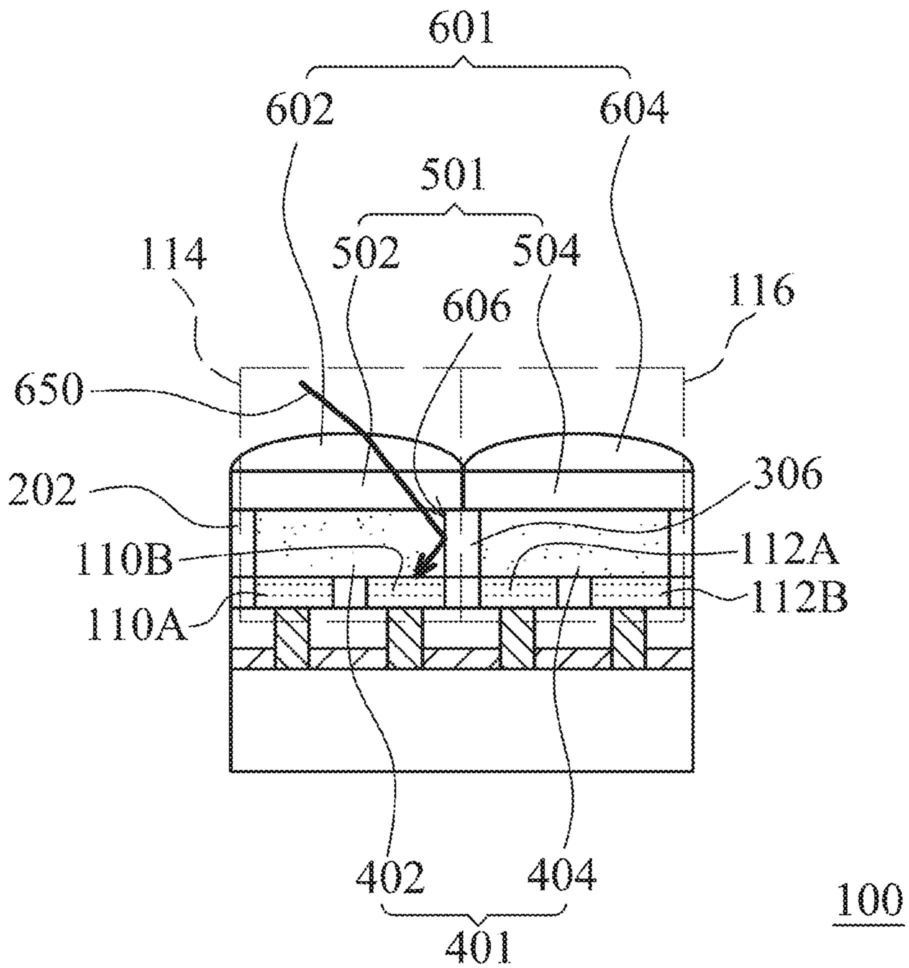

601
602
604
501
502
504
114
606
116
650
202
306
110B
112A
110A
112B
402
404
401
100

Fig.6

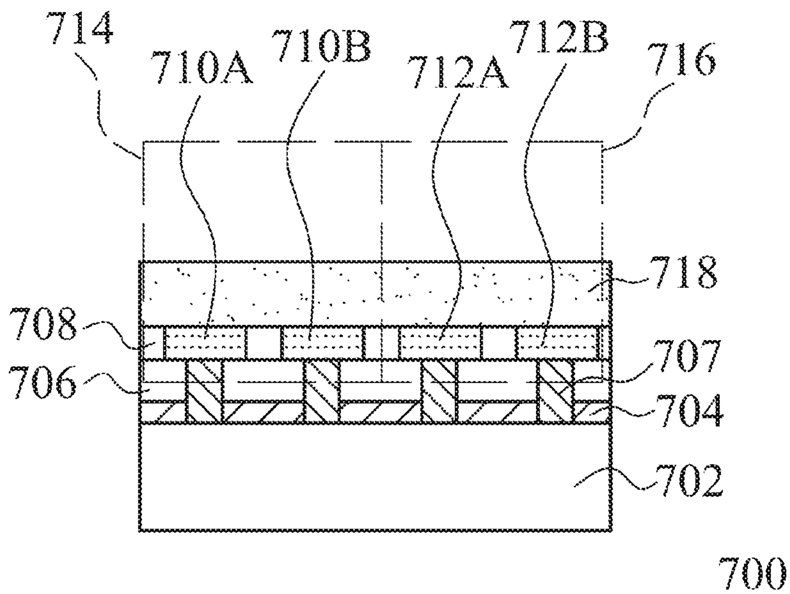



Fig.7

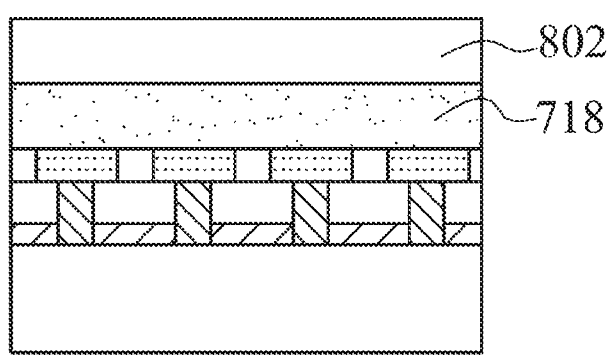



Fig.8

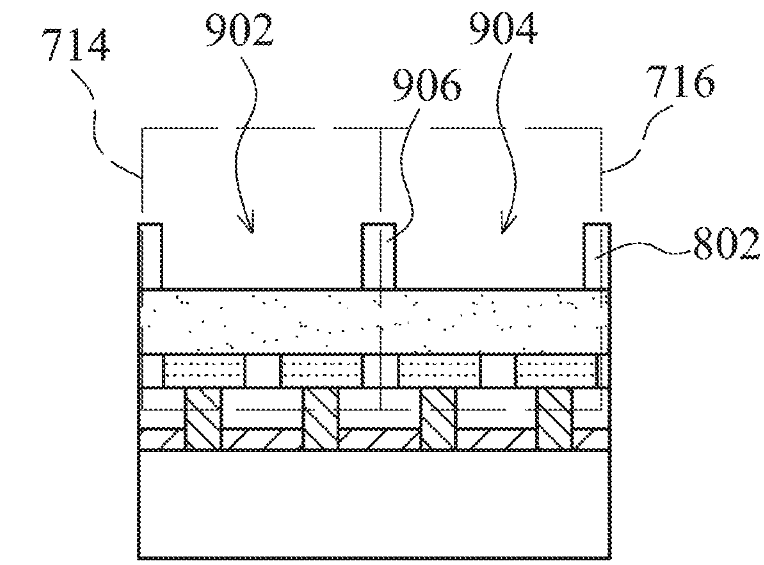



Fig.9

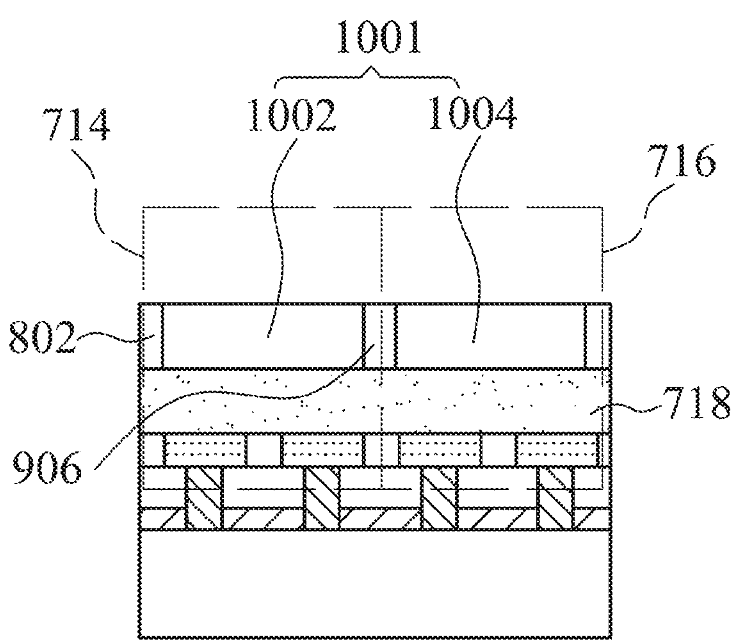



Fig.10

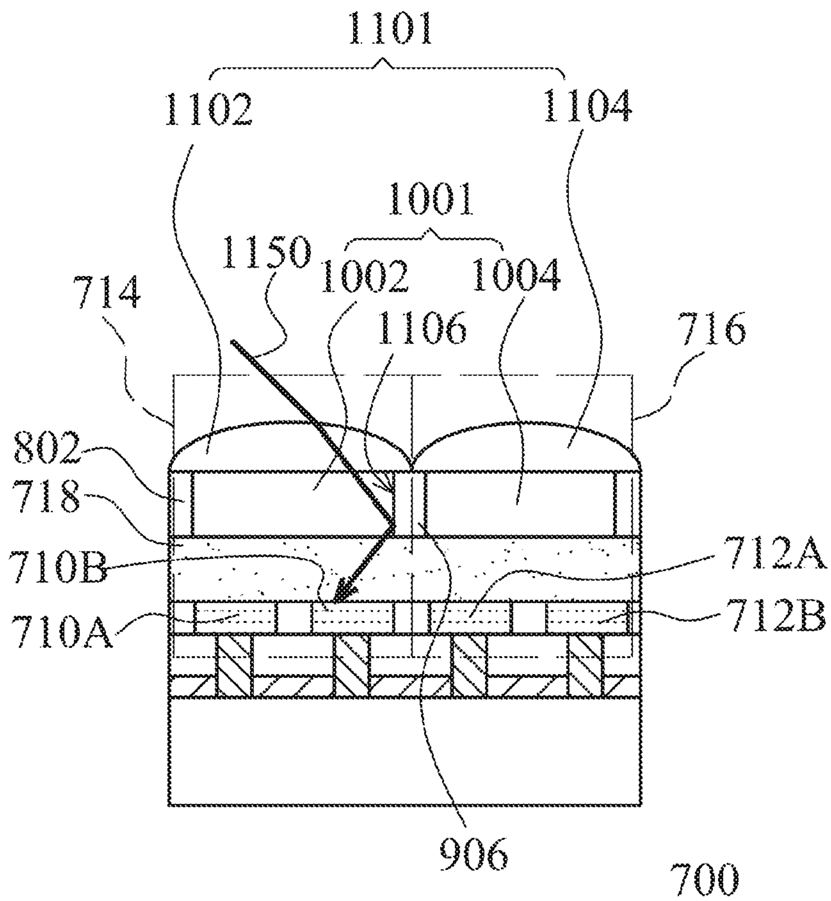
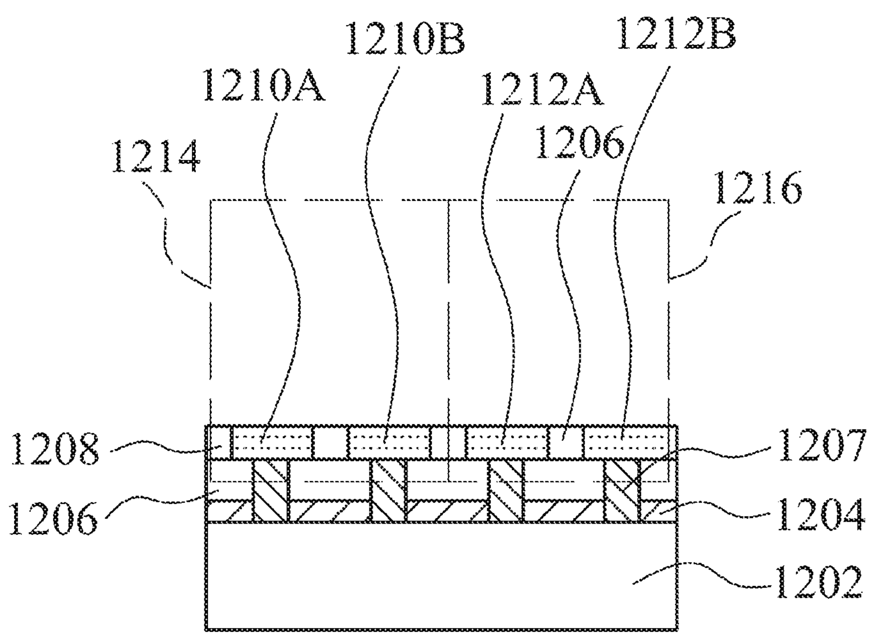

1101
1102
1104
1001
1150
1002
1004
714
1106
716
802
718
710B
712A
710A
712B
906
700

Fig.11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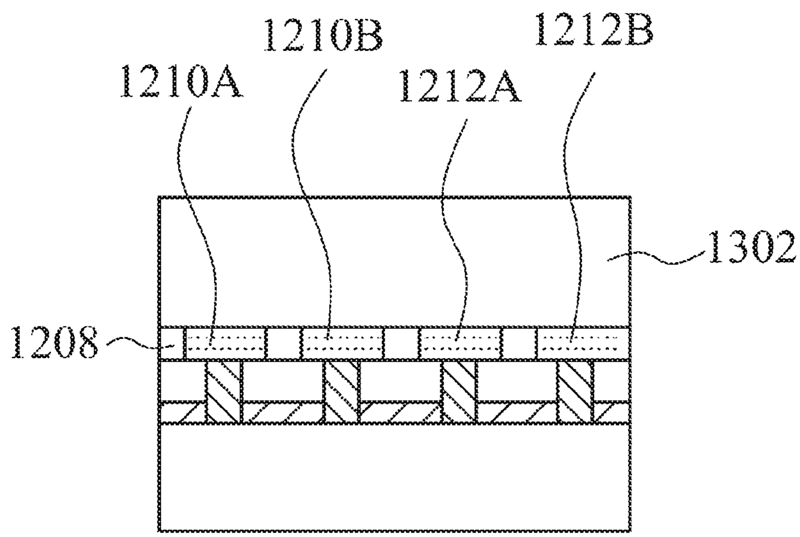
1212A
1206
1214
1216
1208
1207
1206
1204
1202
1200

Fig.12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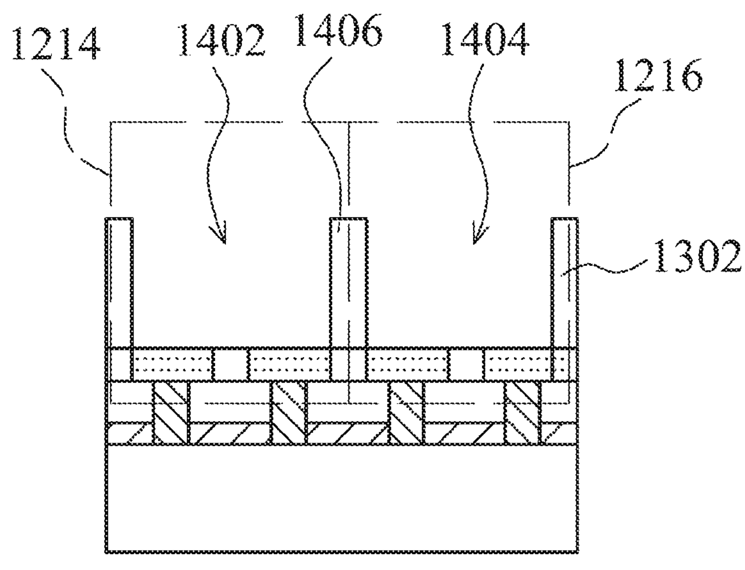
1212A
1302
1208

Fig.13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1402
1406
1404
1216
1302

Fig.14

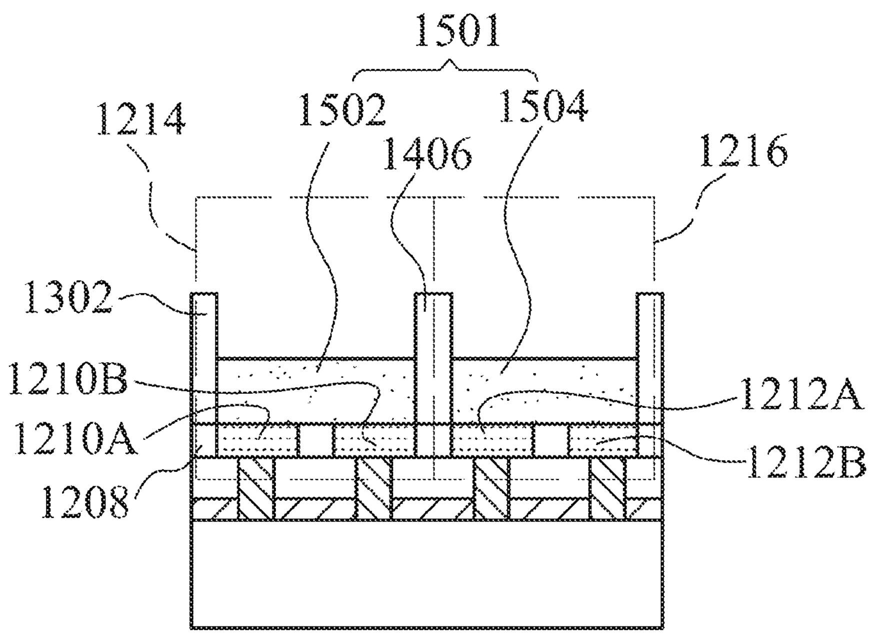

1501
1214
1502
1504
1406
1216
1302
1210B
1212A
1210A
1212B
1208

Fig.15

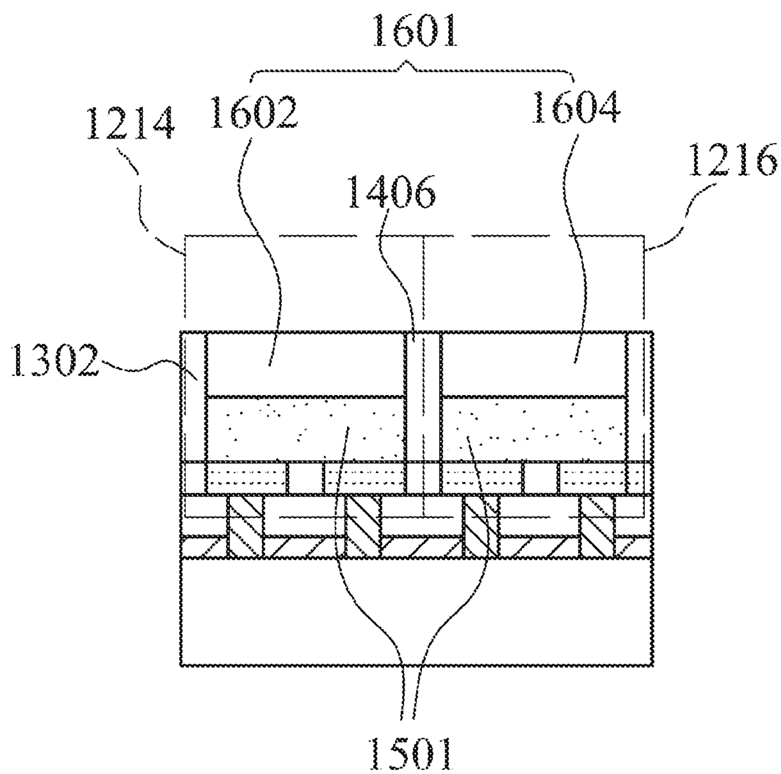



Fig.16

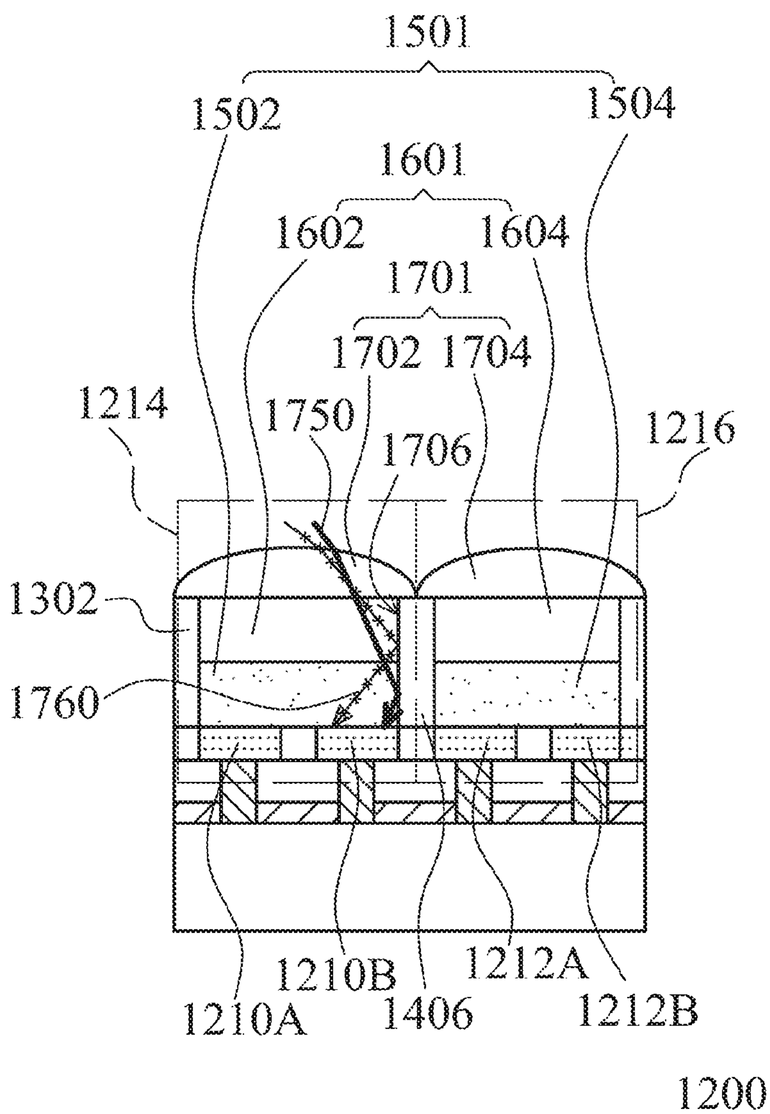
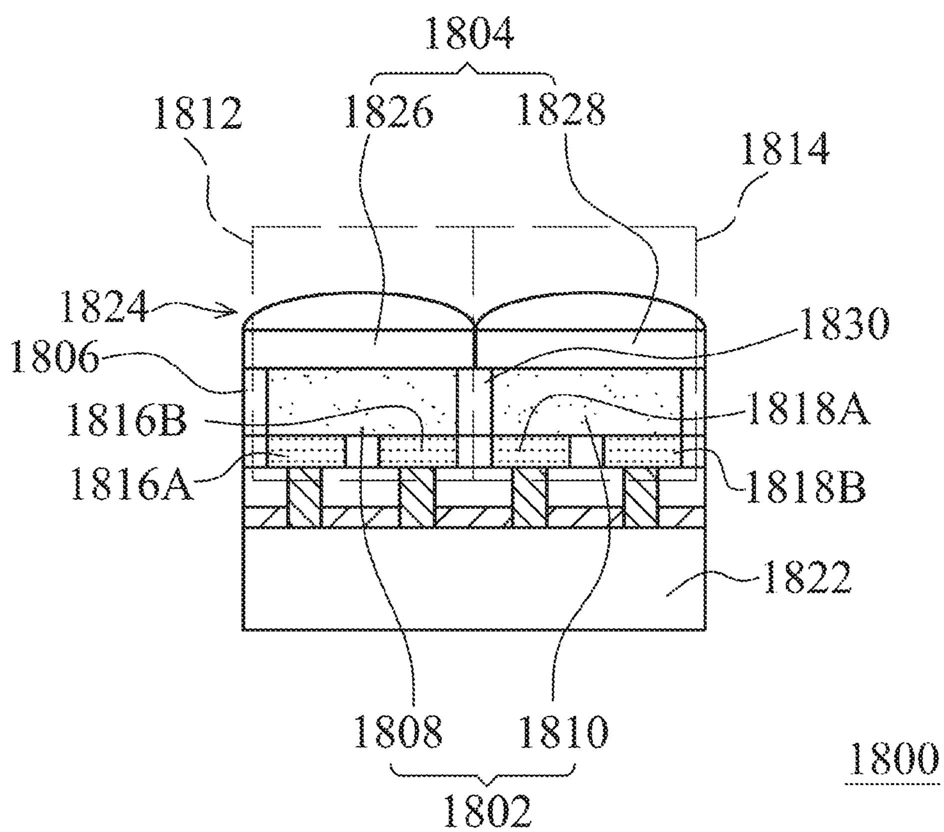

1501
1502
1504
1601
1602
1604
1701
1702
1704
1214
1750
1706
1216
1302
1760
1210B
1212A
1210A
1406
1212B
1200

Fig.17


1804
1812
1826
1828
1814
1824
1830
1806
1816B
1818A
1816A
1818B
1822
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1810
1802
1800

Fig.18

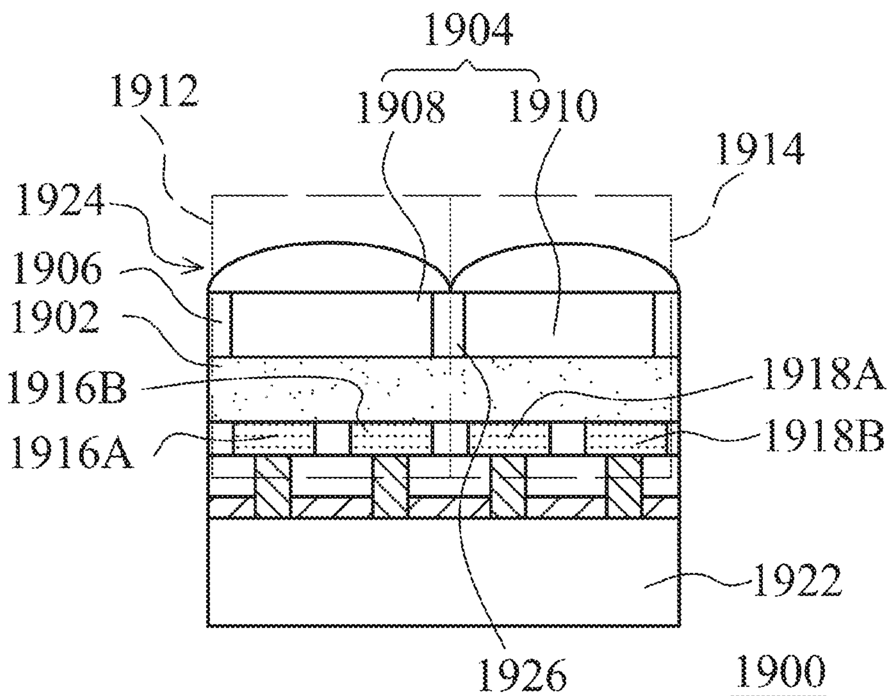
1904
1912
1908
1910
1914
1924
1906
1902
1916B
1918A
1916A
1918B
1922
1926
1900

Fig.19

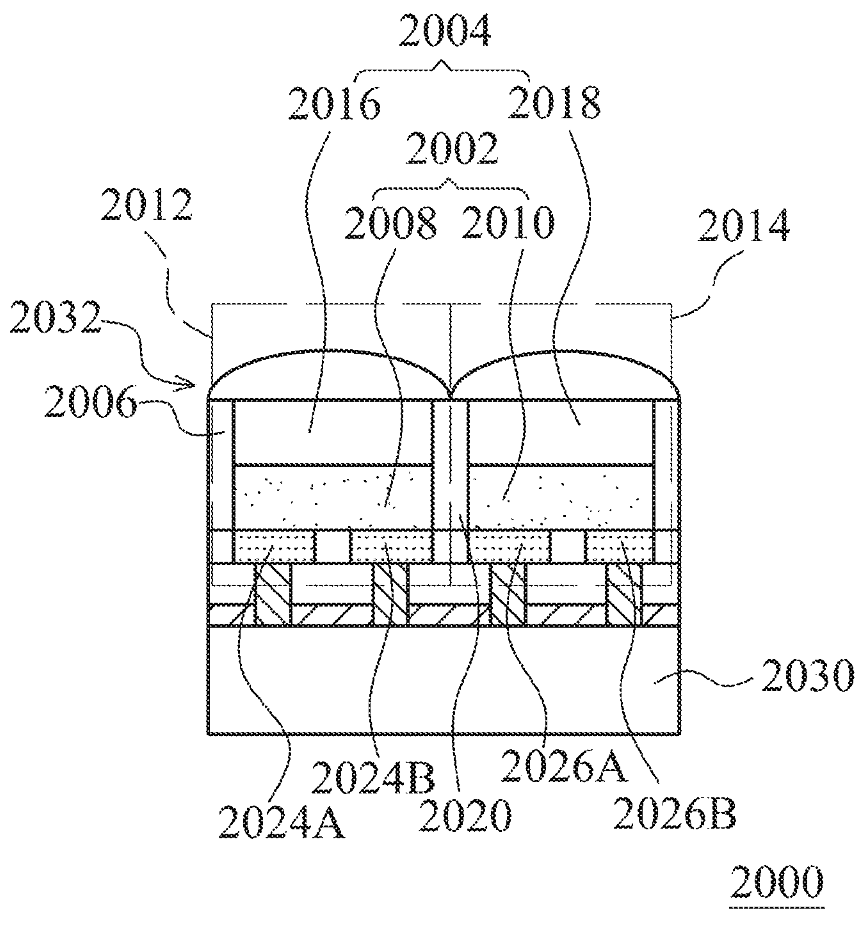
2004
2016
2018
2002
2012
2008
2010
2014
2032
2006
2030
2024B
2026A
2024A
2020
2026B
2000

Fig.20

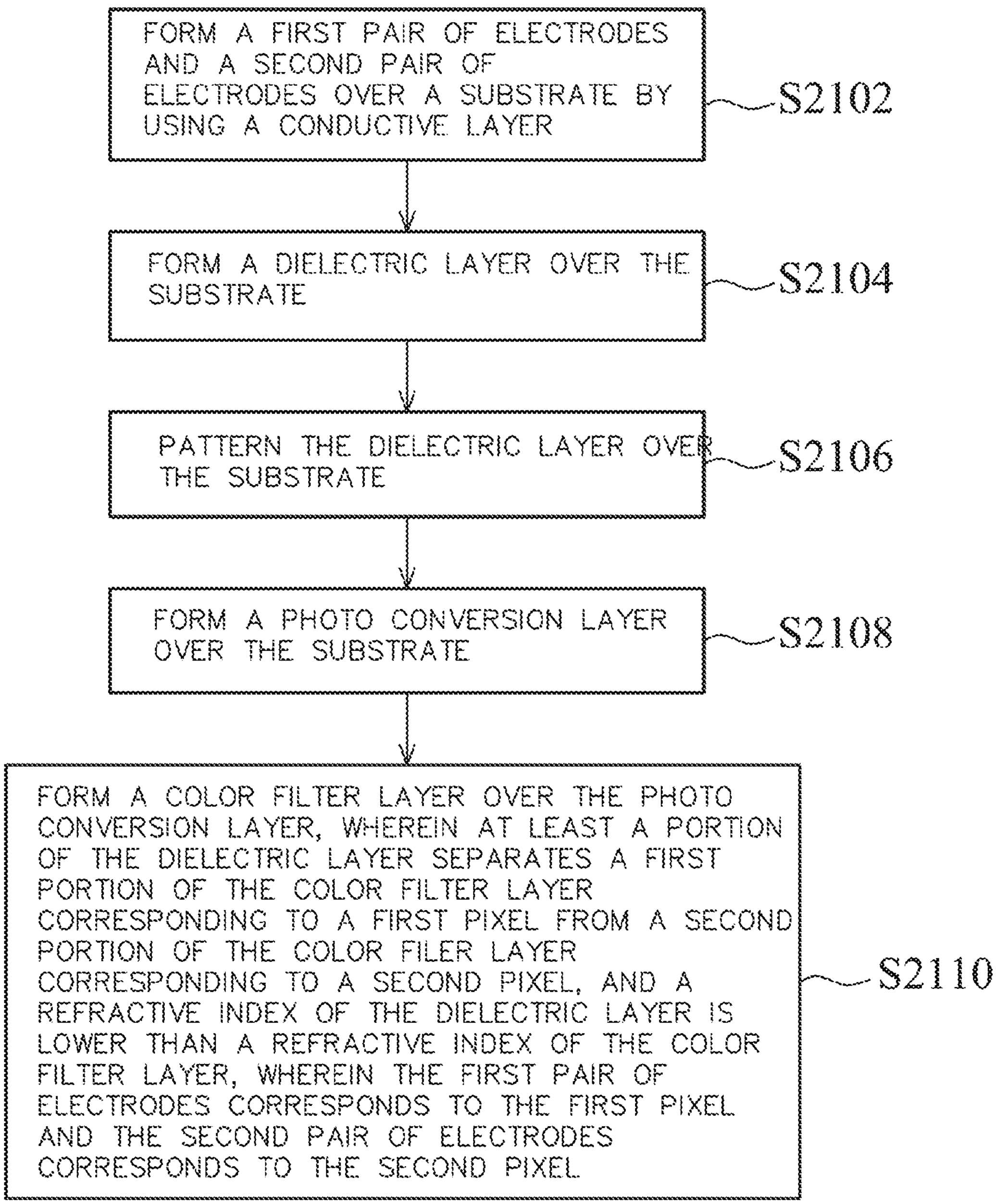
FORM A FIRST PAIR OF ELECTRODES AND A SECOND PAIR OF ELECTRODES OVER A SUBSTRATE BY USING A CONDUCTIVE LAYER
S2102
FORM A DIELECTRIC LAYER OVER THE SUBSTRATE
S2104
PATTERN THE DIELECTRIC LAYER OVER THE SUBSTRATE
S2106
FORM A PHOTO CONVERSION LAYER OVER THE SUBSTRATE
S2108
FORM A COLOR FILTER LAYER OVER THE PHOTO CONVERSION LAYER, WHEREIN AT LEAST A PORTION OF THE DIELECTRIC LAYER SEPARATES A FIRST PORTION OF THE COLOR FILTER LAYER CORRESPONDING TO A FIRST PIXEL FROM A SECOND PORTION OF THE COLOR FILER LAYER CORRESPONDING TO A SECOND PIXEL, AND A REFRACTIVE INDEX OF THE DIELECTRIC LAYER IS LOWER THAN A REFRACTIVE INDEX OF THE COLOR FILTER LAYER, WHEREIN THE FIRST PAIR OF ELECTRODES CORRESPONDS TO THE FIRST PIXEL AND THE SECOND PAIR OF ELECTRODES CORRESPONDS TO THE SECOND PIXEL
S2110

Fig.21

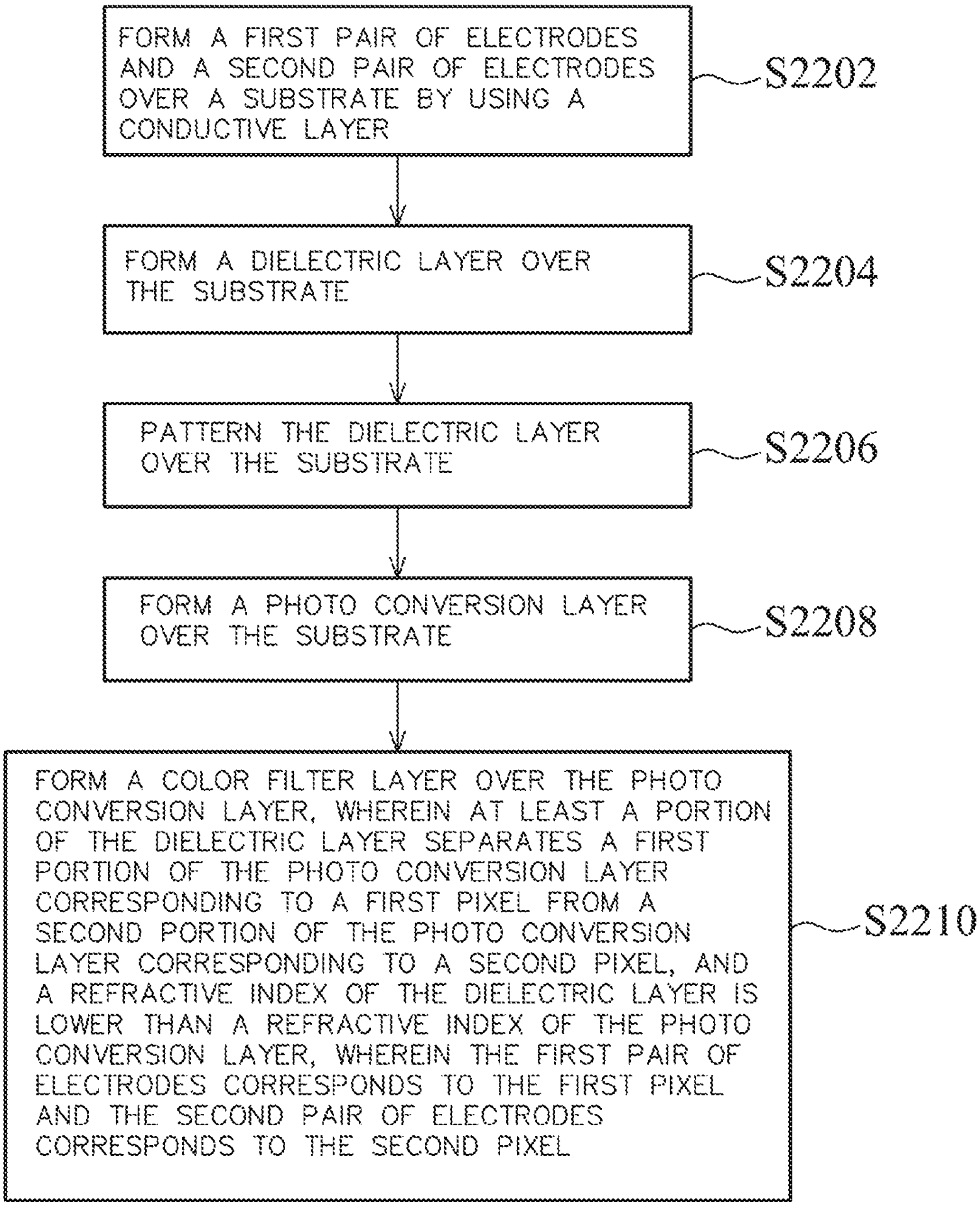
FORM A FIRST PAIR OF ELECTRODES AND A SECOND PAIR OF ELECTRODES OVER A SUBSTRATE BY USING A CONDUCTIVE LAYER
S2202
FORM A DIELECTRIC LAYER OVER THE SUBSTRATE
S2204
PATTERN THE DIELECTRIC LAYER OVER THE SUBSTRATE
S2206
FORM A PHOTO CONVERSION LAYER OVER THE SUBSTRATE
S2208
FORM A COLOR FILTER LAYER OVER THE PHOTO CONVERSION LAYER, WHEREIN AT LEAST A PORTION OF THE DIELECTRIC LAYER SEPARATES A FIRST PORTION OF THE PHOTO CONVERSION LAYER CORRESPONDING TO A FIRST PIXEL FROM A SECOND PORTION OF THE PHOTO CONVERSION LAYER CORRESPONDING TO A SECOND PIXEL, AND A REFRACTIVE INDEX OF THE DIELECTRIC LAYER IS LOWER THAN A REFRACTIVE INDEX OF THE PHOTO CONVERSION LAYER, WHEREIN THE FIRST PAIR OF ELECTRODES CORRESPONDS TO THE FIRST PIXEL AND THE SECOND PAIR OF ELECTRODES CORRESPONDS TO THE SECOND PIXEL
S2210

Fig.22

# PIXEL STRUCTURE OF IMAGE SENSOR HAVING DIELECTRIC LAYER SURROUNDING PHOTO CONVERSION LAYER AND COLOR FILTER

## PRIORITY CLAIM AND CROSS-REFERENCE

This application is a continuation of U.S. patent application Ser. No. 16/223,247, filed on Dec. 18, 2018, entitled "Pixel Structure of Image Sensor and Method of Forming Same", which is a divisional of U.S. patent application Ser. No. 15/088,238, filed on Apr. 1, 2016, entitled "Pixel Structure of Image Sensor and Method of Forming Same", which is a continuation of U.S. patent application Ser. No. 14/731,474, filed on Jun. 5, 2015, now U.S. Pat. No. 9,356,069, issued May 31, 2016, entitled "Photo Diode and Method of Forming the Same", which is a divisional of U.S. patent application Ser. No. 14/014,488, filed Aug. 30, 2013, now U.S. Pat. No. 9,064,989, issued Jun. 23, 2015, entitled "Photo Diode and Method of Forming the Same" all of which are incorporated herein by reference in their entirety.

## FIELD

The technology described in this patent document generally relates to semiconductor processes, and, more particularly, to a photo diode and a method of forming a photo diode.

## BACKGROUND

As photo-electronic technology improves, products using image technology, such as the digital cameras, scanners, and video cameras, have become more popular. In the manufacturing process of image sensors, photo diodes are capable of sensing different colors such as red, green, and blue by means of color filters. Typically, each of the photo diodes senses a specific color only. However, conventional photo diode architecture may suffer serious cross-talk issues because light received from a tilt angle may interfere with adjacent pixels.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1-6** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a first embodiment of the invention.

FIGS. **7-11** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a second embodiment of the invention.

FIGS. **12-17** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a third embodiment of the invention.

FIG. **18** is an exemplary diagram for a photo diode according to a first embodiment of the invention.

FIG. **19** is an exemplary diagram for a photo diode according to a second embodiment of the invention.

FIG. **20** is an exemplary diagram for a photo diode according to a third embodiment of the invention.

FIG. **21** is a flow chart for forming a photo diode according to a first exemplary embodiment of the invention.

FIG. **22** is a flow chart for forming a photo diode according to a second exemplary embodiment of the invention.

## DETAILED DESCRIPTION

Reference will now be made in detail to exemplary embodiments, which are illustrated in the accompanying



drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIGS. **1-6** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a first embodiment of the invention. As shown in FIG. **1**, a read circuit **102** over a substrate (not shown) may be provided in a photo diode **100**. A capping layer **104** for protecting vias **107** in the back end of line process may be provided over the read circuit **102**. The capping layer **104** may be, for example, silicon nitride or silicon carbide. The vias **107** may be, for example, aluminum-copper or copper. A first dielectric layer **106** for electric isolation between the first pair of electrodes **110**A, **110**B and the second pair of electrodes **112**A, **112**B and other metal layers (not shown) in the back end of line process may be provided over the capping layer **104**. A second dielectric layer **108** for electric isolation between the electrodes **110**A, **110**B, **112**A, **112**B may be provided over the first dielectric layer **106**. The dielectric layers **106**, **108** may be, for example, oxide or other isolation materials. The first pair of electrodes **110**A, **110**B and the second pair of electrodes **112**A, **112**B may be any metal or alloy, such as, aluminum-copper and copper. The first pair of electrodes **110**A, **110**B may correspond to a first pixel **114**, and the second pair of electrodes **112**A, **112**B may correspond to a second pixel **116**. The first pair of electrodes **110**A, **110**B and the second pair of electrodes **112**A, **112**B may be formed by the same conductive layer. The first pair of electrodes **110**A, **110**B may include a first positive electrode **110**A and a first negative electrode **110**B, and the second pair of electrodes **112**A, **112**B may include a second positive electrode **112**A and a second negative electrode **112**B.

As shown in FIG. **2**, a third dielectric layer **202** may be provided on the second dielectric layer **108** and the first pair of electrodes **110**A, **110**B and the second pair of electrodes **112**A, **112**B. The third dielectric layer **202** may be also provided over the substrate (not shown).

As shown in FIG. **3**, a mask (not shown) may be used to define an etching region for the third dielectric layer **202**. A portion of the third dielectric layer **202** may be removed by, for example, a dry etching process to form a first grid **302** corresponding to the first pixel **114** and a second grid **304** corresponding to the second pixel **116**. The first grid **302** and the second grid **304** may be separated by a portion **306** of the third dielectric layer **202**.

As shown in FIG. **4**, a photo conversion layer **401** may be formed on the second dielectric layer **108** and the first pair of electrodes **110**A, **110**B and the second pair of electrodes **112**A, **112**B. The portion **306** of the third dielectric layer **202** defines a first portion **402** of the photo conversion layer **401** corresponding to a first pixel **114** from a second portion **404** of the photo conversion layer **401** corresponding to the second pixel **116**. The photo conversion layer **401** may be organic films, such as Phenyl-C61-butyric acid methyl ester (PCBM) or poly(3-hexylthiophene) (P3HT). The refractive index of the third dielectric layer **202** is lower than the refractive index of the photo conversion layer **401**. For example, the refractive index of the photo conversion layer **401** may be about 1.6 to 2, while the refractive index of the third dielectric layer **202** may be smaller than 1.5. In an embodiment of the invention, the thickness of the photo conversion layer **401** may be 100 nanometers to several micrometers.

As shown in FIG. **5**, a color filter layer **501** may be formed over the photo conversion layer **401**. In an embodiment of the invention, a first portion **502** of the color filter layer **501** corresponding to the first pixel **114** may be formed by a red filter process; and a second portion **504** of the color filter layer **501** corresponding to the second pixel **116** may be formed by a green filter process. In an embodiment of the invention, the thickness of the color filter layer **501** may be 0.3 micrometers to 1 micrometers.

As shown in FIG. **6**, a micro lens layer **601** may be formed over the color filter layer **501**. A first portion **602** of the micro lens layer **601** may correspond to the first pixel **114**, and a second portion **604** of the micro lens layer **601** may correspond to the second pixel **116**. In an embodiment of the invention, the photo diode **100** is formed. In the first pixel **114**, bias voltage between the first pair of electrodes **110**A, **110**B may be applied to trigger an electric field that enhances the electrodes **110**A, **110**B in the collection of holes or electrons converted by the first portion **402** of the photo conversion layer **401**. Also, in the second pixel **116**, bias voltage between the second pair of electrodes **112**A, **112**B may be applied to trigger an electric field that enhances the electrodes **112**A, **112**B in the collection of holes or electrons converted by the second portion **404** of the photo conversion layer **401**.

Light through the first portion **602** of the micro lens layer **601**, the first portion **502** of the color filter layer **501**, and the first portion **402** of the photo conversion layer **401** may not pass through the second portion **404** of the photo conversion layer **401** because the portion **306** of third dielectric layer **202** separating the photo conversion layer **401** may change the direction of light.

Total internal reflection may occur and is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. For example, according to the formula

$$\theta_c = \arcsin\frac{n_2}{n_1},$$

assuming that the refractive index (corresponding to n1 in this case) of the photo conversion layer **401** is 2 and the refractive index (corresponding to n2 in this case) of the third dielectric layer **202** is 1.5, the critical angle may be about 49 degrees.

When light **650** strikes the boundary between the photo conversion layer **401** and the portion **306** of the third dielectric layer **202** at an angle larger than the critical angle (49 degrees) with respect to the normal to the lateral surface **606** of the third dielectric layer **202**, light **650** cannot pass through the portion **306** of the third dielectric layer **202** and is reflected. Therefore, light **650** through the first portion **502** of the color filter layer **501** corresponding to the first pixel **114** may not pass through the second portion **404** of the photo conversion layer **401** corresponding to the second pixel **116**. The second pair of electrodes **112**A, **112**B corresponding to the second pixel **116** may not receive holes or electrons converted from light **650** through the first pixel **114**. In an embodiment of the invention, crosstalk of light between the pixels **114**, **116** in the photo diode **100** may be reduced.

FIGS. **7-11** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a second embodiment of the invention. As shown in FIG. **7**, a read circuit **702** over a substrate (not shown) may be provided in the photo diode **700**. A capping layer **704** for protecting vias **707** in the back end of line process may be provided over the read circuit **702**. The capping layer **704** may be, for example, silicon nitride or silicon carbide. The vias **707** may be, for example, aluminum-copper or copper. A first dielectric layer **706** for electric isolation between bottom electrodes **810**, **812** and other metal layers (not shown) in the back end of line process may be provided over the capping layer **804**. A second dielectric layer **708** for electric isolation between the electrodes **710**A, **710**B, **712**A, **712**B may be provided over the first dielectric layer **706**. The dielectric layers **706**, **708** may be, for example, oxide or other isolation materials. The first pair of electrodes **710**A, **710**B and the second pair of electrodes **712**A, **712**B may be any metal or alloy, such as, aluminum-copper and copper. The first pair of electrodes **710**A, **710**B may correspond to a first pixel **714**, and the second pair of electrodes **712**A, **712**B may correspond to a second pixel **716**. The first pair of electrodes **710**A, **710**B and the second pair of electrodes **712**A, **712**B may be formed by the same conductive layer. The first pair of electrodes **710**A, **710**B may include a first positive electrode **710**A and a first negative electrode **710**B, and the second pair of electrodes **712**A, **712**B may include a second positive electrode **712**A and a second negative electrode **712**B.

A photo conversion layer **718** may be formed on the dielectric layer **708**, the first pair of electrodes **710**A, **710**B and the second pair of electrodes **712**A, **712**B. The photo conversion layer **718** may be organic films, such as Phenyl-C61-butyric acid methyl ester (PCBM) or poly(3-hexylthiophene) (P3HT).

As shown in FIG. **8**, a third dielectric layer **802** may be provided on the photo conversion layer **718**. As shown in FIG. **9**, a mask (not shown) may be used to define an etching region for the third dielectric layer **802**. A portion of the third dielectric layer **802** may be removed by, for example, a dry etching process to form a first grid **902** corresponding to the first pixel **714** and a second grid **904** corresponding to the second pixel **716**. The first grid **902** and the second grid **904** may be separated by a portion **906** of the dielectric layer **802**.

As shown in FIG. **10**, a color filter layer **1001** may be formed on the photo conversion layer **718**. In an embodiment of the invention, a first portion **1002** of the color filter layer **1001** corresponding to the first pixel **714** may be formed by a red filter process; and a second portion **1004** of the color filter layer **1001** corresponding to the second pixel **716** may be formed by a green filter process. In an embodiment of the invention, the thickness of the color filter layer **1001** may be 0.3 micrometers to 1 micrometers.

The portion **906** of the dielectric layer **802** defines the first portion **1002** of the color filter layer **1001** corresponding to the first pixel **714** from the second portion **1004** of the color filter layer **1001** corresponding to the second pixel **716**. The refractive index of the third dielectric layer **802** may be lower than the refractive index of the color filter layer **1001**. For example, the refractive index of the color filter layer **1001** may be about 1.6 to 2, while the refractive index of the third dielectric layer **802** may be smaller than 1.5.

As shown in FIG. **11**, a micro lens layer **1101** may be formed over the color filter layer **1001**. A first portion **1102** of the micro lens layer **1101** may correspond to the first pixel **714**, and a second portion **1104** of the micro lens layer **1101** may correspond to the second pixel **716**. In an embodiment of the invention, the photo diode **700** is formed. In the first pixel **714**, bias voltage between the first pair of electrodes **710**A, **710**B may be applied to trigger an electric field that enhances the electrodes **710**A, **710**B in the collection of holes or electrons converted by the photo conversion layer **718**. Also, in the second pixel **716**, bias voltage between the second pair of electrodes **712**A, **712**B may be applied to trigger an electric field that enhances the electrodes **712**A, **712**B in the collection of holes or electrons converted by the photo conversion layer **718**.

Light through the first portion **1102** of the micro lens layer **1101** and the first portion **1002** of the color filter layer **1001** may not pass through the second portion **1004** of the color filter layer **1001** because the portion **906** of third dielectric layer **802** separating the color filter layer **1001** may change the direction of light.

Total internal reflection may occur and is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. For example, according to the formula

$$\theta_c = \arcsin\frac{n_2}{n_1},$$

assuming that the refractive index (corresponding to n1 in this case) of the color filter layer **1001** is 2 and the refractive index (corresponding to n2 in this case) of the third dielectric layer **802** is 1.5, the critical angle may be about 49 degrees. When light **1150** strikes the boundary between the color filter layer **1001** and the portion **1006** of third dielectric layer **802** at an angle larger than the critical angle (49 degrees) with respect to the normal to the lateral surface **1106** of the third dielectric layer **802**, light **1150** cannot pass through the portion **1006** of third dielectric layer **802** and is reflected.

Therefore, light **1150** through the first portion **1002** of the color filter layer **1001** corresponding to the first pixel **714** may not pass through a portion of photo conversion layer **718** corresponding to the second pixel **716**. The second pair of electrodes **712**A, **712**B corresponding to the second pixel **716** may not receive holes or electrons converted from light **1150** through the first pixel **714**. In an embodiment of the invention, crosstalk of light between the pixels **714**, **716** in the photo diode **700** may be reduced.

FIGS. **12-17** are exemplary diagrams during a sequence of processing stages for forming a photo diode according to a third embodiment of the invention. As shown in FIG. **12**, a read circuit **1202** over a substrate (not shown) may be provided in a photo diode **1200**. A capping layer **1204** for protecting vias **1207** in the back end of line process may be provided over the read circuit **1202**. The capping layer **1204** may be, for example, silicon nitride or silicon carbide. The vias **1207** may be, for example, aluminum-copper or copper. A first dielectric layer **1206** for electric isolation between the first pair of electrodes **1210**A, **1210**B and the second pair of electrodes **1212**A, **1212**B and other metal layers (not shown) in the back end of line process may be provided over the capping layer **1204**. A second dielectric layer **1208** for electric isolation between the electrodes **1210**A, **1210**B, **1212**A, **1212**B may be provided over the first dielectric layer **1206**. The dielectric layers **1206**, **1208** may be, for example, oxide or other isolation materials. The first pair of electrodes **1210**A, **1210**B and the second pair of electrodes **1212**A, **1212**B may be any metal or alloy, such as, aluminum-copper and copper. The first pair of electrodes **1210**A, **1210**B may correspond to a first pixel **1214**, and the second pair of electrodes **1212**A, **1212**B may correspond to a second pixel **1216**. The first pair of electrodes **1210**A, **1210**B and the second pair of electrodes **1212**A, **1212**B may be formed by the same conductive layer. The first pair of electrodes **1210**A, **1210**B may include a first positive electrode **1210**A and a first negative electrode **1210**B, and the second pair of electrodes **1212**A, **1212**B may include a second positive electrode **1212**A and a second negative electrode **1212**B.

As shown in FIG. **13**, a third dielectric layer **1302** may be provided on the second dielectric layer **1208** and the first pair of electrodes **1210**A, **1210**B and the second pair of electrodes **1212**A, **1212**B. The third dielectric layer **1302** may be also provided over the substrate (not shown).

As shown in FIG. **14**, a mask (not shown) may be used to define an etching region for the third dielectric layer **1302**. A portion of the third dielectric layer **1302** may be removed by, for example, a dry etching process to form a first grid **1402** corresponding to the first pixel **1214** and a second grid **1404** corresponding to the second pixel **1216**. The first grid **1402** and the second grid **1404** may be separated by a portion **1406** of the third dielectric layer **1302**.

As shown in FIG. **15**, a photo conversion layer **1501** may be formed on the second dielectric layer **1208** and the first pair of electrodes **1210**A, **1210**B and the second pair of electrodes **1212**A, **1212**B. The portion **1406** of the third dielectric layer **1302** defines a first portion **1502** of the photo conversion layer **1501** corresponding to the first pixel **1214** from a second portion **1504** of the photo conversion layer **1501** corresponding to the second pixel **1216**. The photo conversion layer **1501** may be organic films, such as Phenyl-C61-butyric acid methyl ester (PCBM) or poly(3-hexylthiophene) (P3HT). The refractive index of the third dielectric layer **1302** is lower than the refractive index of the photo conversion layer **1501**. For example, the refractive index of the photo conversion layer **1501** may be about 1.6 to 2, while the refractive index of the third dielectric layer **1302** may be smaller than 1.5. In an embodiment of the invention, the thickness of the photo conversion layer **1501** may be 100 nanometers to several micrometer.

As shown in FIG. **16**, a color filter layer **1601** may be formed on the photo conversion layer **1501**. In an embodiment of the invention, a first portion **1602** of the color filter layer **1601** corresponding to the first pixel **1214** may be formed by a red filter process; and a second portion **1604** of the color filter layer **1601** corresponding to the second pixel **1216** may be formed by a green filter process. In an embodiment of the invention, the thickness of the color filter layer **1601** may be 0.3 micrometers to 1 micrometers.

The portion **1406** of the third dielectric layer **1302** defines a first portion **1602** of the color filter layer **1601** corresponding to the first pixel **1214** from a second portion **1604** of the color filter layer **1601** corresponding to the second pixel **1216**. The refractive index of the third dielectric layer **1302** is lower than the refractive index of the color filter layer **1601**. For example, the refractive index of the color filter layer **1601** may be about 1.6 to 2, while the refractive index of the third dielectric layer **1302** may be smaller than 1.5.

As shown in FIG. **17**, a micro lens layer **1701** is formed over the color filter layer **1601**. A first portion **1702** of the micro lens layer **1701** may correspond to a first pixel **1214**, and the second portion **1704** of the micro lens layer **1701** may correspond to a second pixel **1216**. In an embodiment of the invention, the photo diode **1200** is formed. In the first pixel **1214**, bias voltage between the first pair of electrodes **1210**A, **1210**B may be applied to trigger an electric field that enhances the electrodes **1210**A, **1210**B in the collection of holes or electrons converted by the first portion **1502** of the photo conversion layer **1501**. Also, in the second pixel **716**, bias voltage between the second pair of electrodes **1212**A, **1212**B may be applied to trigger an electric field that enhances the electrodes **1212**A, **1212**B in the collection of holes or electrons converted by the second portion **1504** of the photo conversion layer **1501**.

Light through the first portion **1702** of the micro lens layer **1701**, the first portion **1602** of the color filter layer **1601** and the first portion **1502** of the photo conversion layer **1501** may not pass through the second portion **1504** of the photo conversion layer **1501** because the portion **1406** of third dielectric layer **1302** separating the photo conversion layer **1501** may change the direction of the light.

Total internal reflection may occur and is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. For example, according to the formula

$$\theta_c = \arcsin\frac{n_2}{n_1},$$

assuming that the refractive index (corresponding to n1 in this case) of the photo conversion layer **1501** is 2 and the refractive index (corresponding to n2 in this case) of the third dielectric layer **1302** is 1.5, the critical angle may be about 49 degrees. When light **1750** strikes the boundary between the photo conversion layer **1501** and the portion **1406** of third dielectric layer **1302** at an angle larger than the critical angle (49 degrees) with respect to the normal to the lateral surface **1706** of the third dielectric layer **1302**, light **1750** cannot pass through the portion **1406** of third dielectric layer **1302** and is reflected. Therefore, light **1750** through the first portion **1502** of the color filter layer **1501** corresponding to the first pixel **1214** may not pass through the second portion **1504** of the photo conversion layer **1501** corresponding to the second pixel **1216**. The second pair of electrodes **1212**A, **1212**B corresponding to the second pixel **1216** may not receive holes or electrons converted from light **1750** through the first pixel **1214**. In an embodiment of the invention, crosstalk of light between the pixels **1214**, **1216** in the photo diode **1200** may be reduced.

Light through the first portion **1702** of the micro lens layer **1701** and the first portion **1602** of the color filter layer **1601** may not pass through the second portion **1604** of the color filter layer **1601** because the portion **1406** of third dielectric layer **1302** separating the color filter layer **1001** may change the direction of light.

In an embodiment of the invention, according to the formula

$$\theta_c = \arcsin\frac{n_2}{n_1},$$

assuming that the refractive index (corresponding to n1 in this case) of the color filter layer **1601** is 2 and the refractive index (corresponding to n2 in this case) of the third dielectric layer **1302** is 1.5, the critical angle may be about 49 degrees. When light **1760** strikes the boundary between the color filter layer **1601** and the portion **1406** of third dielectric layer **1302** at an angle larger than the critical angle (49 degrees) with respect to the normal to the lateral surface **1706** of the third dielectric layer **1302**, light **1760** cannot pass through the portion **1406** of the third dielectric layer **1302** and is reflected.

Therefore, light **1760** through the first portion **1602** of the color filter layer **1601** corresponding to the first pixel **1214** may not pass through the second portion **1504** of the photo conversion layer **1501** corresponding to the second pixel **1216**. The second pair of electrodes **1212**A, **1212**B corresponding to the second pixel **1216** may not receive holes or electrons converted from light **1760** through the first pixel **1214**. In an embodiment of the invention, crosstalk of light between the pixels **1214**, **1216** in the photo diode **1200** may be also reduced.

FIG. **18** is an exemplary diagram for a photo diode according to a first embodiment of the invention. As shown in FIG. **18**, a photo diode **1800** may include a substrate (not shown), a photo conversion layer **1802**, a color filter layer **1804** and a dielectric layer **1806**. The photo conversion layer **1802** is disposed over the substrate (not shown). The color filter layer **1804** is disposed over the photo conversion layer **1802**. A portion **1830** of the dielectric layer **1806** defines a first portion **1808** of the photo conversion layer **1802** corresponding to a first pixel **1812** from a second portion **1810** of the photo conversion layer **1802** corresponding to a second pixel **1814**. The refractive index of the dielectric layer **1806** may be lower than the refractive index of the photo conversion layer **1802**.

In an embodiment of the invention, the photo diode **1800** further includes a first pair of electrodes **1816**A, **1816**B and a second pair of electrodes **1818**A, **1818**B disposed over the substrate (not shown). The first pair of electrodes **1816**A, **1816**B may correspond to the first pixel **1812**, and the second pair of electrodes **1818**A, **1818**B may correspond to the second pixel **1814**. In an embodiment of the invention, the photo conversion layer **1802** is an organic film layer. In an embodiment of the invention, the photo diode **1800** further includes a read out circuit **1822**. The read out circuit **1822** is disposed over the substrate (not shown). In an embodiment of the invention, the photo diode **1800** further includes a micro lens layer **1824**. The micro lens layer **1824** is disposed over the color filter layer **1804**. In an embodiment of the invention, a first portion **1826** of the color filter layer **1804** corresponding to the first pixel **1812** is a red filter, and a second portion **1828** of the color filter layer **1804** corresponding to the second pixel **1814** is a green filter. In an embodiment of the invention, the dielectric layer **1806** includes a first grid corresponding to the first pixel **1812** and a second grid corresponding to the second pixel **1814**. In an embodiment of the invention, the first pair of electrodes **1816**A, **1816**B may include a first positive electrode **1816**A and a first negative electrode **1816**B, and the second pair of electrodes **1818**A, **1818**B may include a second positive electrode **1818**A and a second negative electrode **1818**B.

FIG. **19** is an exemplary diagram for a photo diode according to a second embodiment of the invention. As shown in FIG. **19**, another photo diode **1900** includes a substrate (not shown), a photo conversion layer **1902**, a color filter layer **1904** and a dielectric layer **1906**. The photo conversion layer **1902** is disposed over the substrate (not shown). The color filter layer **1904** is disposed over the photo conversion layer **1902**. A portion **1926** of the dielectric layer **1906** defines a first portion **1908** of the color filter layer **1904** corresponding to a first pixel **1912** from a second portion **1910** of the color filter layer **1904** corresponding to a second pixel **1914**. The refractive index of the dielectric layer **1906** is lower than the refractive index of the color filter layer **1904**.

In an embodiment of the invention, the photo diode **1900** further includes a first pair of electrodes **1916**A, **1916**B and a second pair of electrodes **1918**A, **1918**B disposed over the substrate (not shown). The first pair of electrodes **1916**A, **1916**B may correspond to the first pixel **1912**, and the second pair of electrodes **1918**A, **1918**B may correspond to the second pixel **1914**. In an embodiment of the invention, the photo conversion layer **1902** is an organic film layer. In an embodiment of the invention, the photo diode **1900** further includes a read out circuit **1922**. The read out circuit **1922** is disposed over the substrate (not shown). In an embodiment of the invention, the photo diode **1900** further includes a micro lens layer **1924**. The micro lens layer **1924** is disposed over the color filter layer **1904**. In an embodiment of the invention, the first portion **1908** of the color filter layer **1904** corresponding to the first pixel **1912** is a red filter, and the second portion **1910** of the color filter layer **1904** corresponding to the second pixel **1914** is a green filter. In an embodiment of the invention, the dielectric layer **1906** includes a first grid corresponding to the first pixel **1912** and a second grid corresponding to the second pixel **1914**. In an embodiment of the invention, the first pair of electrodes **1916**A, **1916**B may include a first positive electrode **1916**A and a first negative electrode **1916**B, and the second pair of electrodes **1918**A, **1918**B may include a second positive electrode **1918**A and a second negative electrode **1918**B.

FIG. **20** is an exemplary diagram for a photo diode according to a third embodiment of the invention. As shown in FIG. **20**, another photo diode **2000** includes a substrate (not shown), a photo conversion layer **2002**, a color filter layer **2004** and a dielectric layer **2006**. The photo conversion layer **2002** is disposed over the substrate (not shown). The color filter layer **2004** is disposed over the photo conversion layer **2002**. A portion **2020** of the dielectric layer **2006** defines a first portion **2008** of the photo conversion layer **2002** corresponding to a first pixel **2012** from a second portion **2010** of the photo conversion layer **2002** corresponding to a second pixel **2014**. The refractive index of the dielectric layer **2006** is lower than the refractive index of the photo conversion layer **2002** and the refractive index of the color filter layer **2004**. The portion **2020** of the dielectric layer **2006** also defines a first portion **2016** of the color filter layer **2004** corresponding to the first pixel **2012** from a second portion **2018** of the color filter layer **2004** corresponding to the second pixel **2014**.

In an embodiment of the invention, the photo diode **2000** further includes a first pair of electrodes **2024**A, **2024**B and a second pair of electrodes **2026**A, **2026**B disposed over the substrate (not shown). The first pair of electrodes **2024**A, **2024**B may correspond to the first pixel **2012**, and the second pair of electrodes **2026**A, **2026**B may correspond to the second pixel **2014**. In an embodiment of the invention, the photo conversion layer **2002** is an organic film layer. In an embodiment of the invention, the photo diode **2000** further includes a read out circuit **2030**. The read out circuit **2030** is disposed over the substrate (not shown). In an embodiment of the invention, the photo diode **2000** further includes a micro lens layer **2032**. The micro lens layer **2032** is disposed over the color filter layer **2004**. In an embodiment of the invention, a first portion **2016** of the color filter layer **2004** corresponding to the first pixel **2012** is a red filter, and the second portion **2018** of the color filter layer **2004** corresponding to the second pixel **2014** is a green filter. In an embodiment of the invention, the dielectric layer **2006** includes two grids. Each of the grids the dielectric layer **2006** respectively may correspond to the first pixel **2012** and the second pixel **2014**. In an embodiment of the invention, the first pair of electrodes **2024**A, **2024**B may include a first positive electrode **2024**A and a first negative electrode **2024**B, and the second pair of electrodes **2026**A, **2026**B may include a second positive electrode **2026**A and a second negative electrode **2026**B.

FIG. **21** is a flow chart for forming a photo diode according to a first exemplary embodiment of the invention. As shown in FIG. **21**, the method **2100** for forming a photo diode is provided. The method **2100** may include the following procedures: forming a first pair of electrodes and a second pair of electrodes over a substrate by using a conductive layer (S**2102**); forming a dielectric layer over the substrate (S**2104**); patterning the dielectric layer over the substrate (S**2106**); forming a photo conversion layer over the substrate (S**2108**); and forming a color filter layer over the photo conversion layer, wherein at least a portion of the dielectric layer separates a first portion of the color filter layer corresponding to a first pixel from a second portion of the color filter layer corresponding to a second pixel, and a refractive index of the dielectric layer is lower than a refractive index of the color filter layer, wherein the first pair of electrodes corresponds to the first pixel and the second pair of electrodes corresponds to the second pixel (S**2110**).

FIG. **22** is a flow chart for forming a photo diode according to a second exemplary embodiment of the invention. As shown in FIG. **22**, the method **2200** for forming a photo diode is provided. The method **2200** may include the following procedures: forming a first pair of electrodes and a second pair of electrodes over a substrate by using a conductive layer (S**2202**); forming a dielectric layer over the substrate (S**2204**); patterning the dielectric layer over the substrate (S**2206**); forming a photo conversion layer over the substrate (S**2208**); and forming a color filter layer over the photo conversion layer, wherein at least a portion of the dielectric layer separates a first portion of the photo conversion layer corresponding to a first pixel from a second portion of the photo conversion layer corresponding to a second pixel, and a refractive index of the dielectric layer is lower than a refractive index of the photo conversion layer, wherein the first pair of electrodes corresponds to the first pixel and the second pair of electrodes corresponds to the second pixel (S**2210**).

An exemplary photo diode comprises a pixel unit that includes a pair of pixels, a photo conversion layer that is above the pixel unit and that has a pair of portions, each of which corresponds to a respective one of the pixels, and a dielectric layer that is between the portions of the photo conversion layer.

Another exemplary photo diode comprises a pixel unit that includes a pair of pixels, a color filter that is above the pixel unit and that has a pair of portions, each of which corresponds to a respective one of the pixels, and a dielectric layer that is between the portions of the color filter.

An exemplary method of manufacturing a photo diode comprises forming a pixel unit that includes a pair of pixels, forming a dielectric layer above the pixel unit, forming above the pixel unit a photo conversion layer and a color filter, each of which has a pair of portions that respectively correspond to the pixels, and patterning the dielectric layer such that the dielectric layer is between the portions of at least one of the photo conversion layer and the color filter.

An exemplary method includes forming a dielectric layer over a substrate. The dielectric layer is patterned to form a plurality of openings in the dielectric layer. A photo conversion layer and a color filter layer are formed in the plurality of openings. An interface between the photo conversion layer and the color filter layer is below a topmost surface of the dielectric layer.

An exemplary method includes forming an electrode layer over a substrate. A dielectric layer is formed over the electrode layer. The dielectric layer is patterned to form a plurality of openings in the dielectric layer. A photo conversion layer is formed in the plurality of openings. A topmost surface of the photo conversion layer is below a topmost surface of the dielectric layer. A color filter layer is formed in remaining portions of the plurality of openings.

An exemplary method includes forming a plurality of electrodes over a substrate. A dielectric layer is formed over the plurality of electrodes. The dielectric layer is etched to form a first opening and a second opening in the dielectric layer. The first opening exposes a first pair of the plurality of electrodes. The second opening exposes a second pair of the plurality of electrodes. A first photo conversion layer is formed in the first opening. A thickness of the first photo conversion layer is less than a thickness of the dielectric layer. A second photo conversion layer is formed in the second opening. A thickness of the second photo conversion layer is less than the thickness of the dielectric layer. A first color filter layer is formed over the first photo conversion layer. A second color filter layer is formed over the second photo conversion layer. A portion of the dielectric layer is interposed between the first color filter layer and the second color filter layer.

An exemplary semiconductor structure includes a photo conversion layer over a substrate, a color filter over and in physical contact with the photo conversion layer, and a dielectric layer surrounding the photo conversion layer and the color filter. A topmost surface of the dielectric layer is above an interface between the photo conversion layer and the color filter.

An exemplary semiconductor structure includes a photo conversion layer over a substrate, a color filter over the photo conversion layer, and a dielectric layer extending along and in physical contact with sidewalls of the photo conversion layer and sidewalls of the color filter. A topmost surface of the dielectric layer is above a topmost surface of the photo conversion layer.

An exemplary semiconductor structure includes a pair of electrodes over a substrate, a photo conversion layer over the pair of electrodes, a color filter over the photo conversion layer, a dielectric layer surrounding the photo conversion layer and the color filter, and a micro lens over and in physical contact with the color filter and the dielectric layer. A thickness of the dielectric layer is greater than a thickness of the photo conversion layer.

This written description uses examples to disclose the disclosure, include the best mode, and also to enable a person skilled in the art to make and use the disclosure. The patentable scope of the disclosure may include other examples that occur to those skilled in the art.

One skilled in the relevant art will recognize that the various embodiments may be practiced without one or more of the specific details, or with other replacement and/or additional methods, materials, or components. Well-known structures, materials, or operations may not be shown or described in detail to avoid obscuring aspects of various embodiments of the disclosure. Various embodiments shown in the figures are illustrative example representations and are not necessarily drawn to scale. Particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments. Various additional layers and/or structures may be included and/or described features may be omitted in other embodiments. Various operations may be described as multiple discrete operations in turn, in a manner that is most helpful in understanding the disclosure. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation. Operations described herein may be performed in a different order, in series or in parallel, than the described embodiment. Various additional operations may be performed and/or described. Operations may be omitted in additional embodiments.



This written description and the following claims may include terms, such as left, right, top, bottom, over, under, upper, lower, first, second, etc. that are used for descriptive purposes only and are not to be construed as limiting. For example, terms designating relative vertical position may refer to a situation where a device side (or active surface) of a substrate or integrated circuit is the "top" surface of that substrate; the substrate may actually be in any orientation so that a "top" side of a substrate may be lower than the "bottom" side in a standard terrestrial frame of reference and may still fall within the meaning of the term "top." The term "on" as used herein (including in the claims) may not indicate that a first layer "on" a second layer is directly on and in immediate contact with the second layer unless such is specifically stated; there may be a third layer or other structure between the first layer and the second layer on the first layer. The embodiments of a device or article described herein may be manufactured, used, or shipped in a number of positions and orientations. Persons skilled in the art will recognize various equivalent combinations and substitutions for various components shown in the figures.

What is claimed is:

**1**. A semiconductor structure comprising:
a photo conversion layer over a substrate;
a color filter over and in physical contact with the photo conversion layer, wherein the photo conversion layer and the color filter have a same width; and
a dielectric layer surrounding the photo conversion layer and the color filter, a topmost surface of the dielectric layer being above an interface between the photo conversion layer and the color filter.

**2**. The semiconductor structure of claim **1**, further comprising a micro lens in physical contact with the topmost surface of the dielectric layer and a topmost surface of the color filter.

**3**. The semiconductor structure of claim **1**, wherein the dielectric layer is in physical contact with sidewalls of the photo conversion layer and sidewalls of the color filter.

**4**. The semiconductor structure of claim **1**, further comprising a pair of electrodes interposed between the substrate and the photo conversion layer.

**5**. The semiconductor structure of claim **1**, wherein the photo conversion layer comprises an organic film.

**6**. The semiconductor structure of claim **1**, wherein a refractive index of the dielectric layer is less than a refractive index of the photo conversion layer.

**7**. The semiconductor structure of claim **6**, wherein the refractive index of the dielectric layer is less than a refractive index of the color filter.

**8**. A semiconductor structure comprising:
a photo conversion layer over a substrate;
a color filter over and in physical contact with the photo conversion layer; and
a dielectric layer extending along and in physical contact with sidewalls of the photo conversion layer and sidewalls of the color filter, a topmost surface of the dielectric layer being above a topmost surface of the photo conversion layer.

**9**. The semiconductor structure of claim **8**, further comprising a plurality of electrodes interposed between the substrate and the photo conversion layer.

10. The semiconductor structure of claim 9, further comprising a plurality of conductive vias over the substrate, wherein each of the plurality of conductive vias is in physical contact with a corresponding one of the plurality of electrodes.

11. The semiconductor structure of claim 8, further comprising a micro lens over the dielectric layer and the color filter.

12. The semiconductor structure of claim 8, wherein a refractive index of the color filter is between about 1.6 to about 2.

13. The semiconductor structure of claim 12, wherein a refractive index of the photo conversion layer is between about 1.6 to about 2.

14. The semiconductor structure of claim 13, wherein a refractive index of the dielectric layer is less than about 1.5.

15. A semiconductor structure comprising:

a pair of electrodes over a substrate;

a photo conversion layer over the pair of electrodes;

a color filter over the photo conversion layer, wherein the photo conversion layer and the color filter have a same width;

a dielectric layer surrounding the photo conversion layer and the color filter, a thickness of the dielectric layer being greater than a thickness of the photo conversion layer; and

a micro lens over and in physical contact with the color filter and the dielectric layer.

16. The semiconductor structure of claim 15, wherein a thickness of the color filter is between about 0.3 μm and about 1 μm.

17. The semiconductor structure of claim 15, wherein the dielectric layer is in physical contact with sidewalls of the photo conversion layer, sidewalls of the color filter and a bottom surface of the micro lens.

18. The semiconductor structure of claim 15, wherein a first electrode of the pair of electrodes is laterally spaced apart from a second electrode of the pair of electrodes.

19. The semiconductor structure of claim 15, further comprising a pair of conductive vias interposed between the photo conversion layer and the substrate, wherein a first conductive via of the pair of conductive vias is in physical contact with a first electrode of the pair of electrodes, and wherein a second conductive via of the pair of conductive vias is in physical contact with a second electrode of the pair of electrodes.

20. The semiconductor structure of claim 15, wherein the photo conversion layer comprises an organic material.

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